

Clustering of absorption line systems

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Abstract. Absorption line systems are luminosity unbiased tracers of the spatial distribution of baryons over most of the history of the Universe. I review the importance of studying the clustering properties of the absorbers and the impact of VLT in this subject. The primary aim of the project is to track the evolution of the structures of the Universe back in time.

1 Introduction

Evolution of large scale structures of the Universe is one of the most important issues of modern cosmology. QSO absorption line systems probe material lying on the line of sight to quasars over a large redshift range ($0 < z < 5$). The systems where metal lines are detected have been recognized to be associated with haloes of galaxies (e.g. Bergeron & Boissé 1991, Steidel 1993). Those with very low metal content (the Ly α forest), are generally believed to probe intergalactic gas. Part of this gas could be associated with galaxies however, but how is yet unclear (e.g. Lanzetta et al. 1994, Le Brun et al. 1995, Charlton et al. 1995). In any case, the absorption line systems can be used as luminosity unbiased tracers of the spatial distribution of baryons over most of the history of the Universe. To do so background sources at small projected distances on the sky should be observed to study correlation between absorptions detected along different lines of sight. When the sources are very close (for example two images of the same gravitationally lensed quasar), the lines of sight probe the same clouds and information on the perpendicular sizes and the internal structure of the clouds can be derived. With sources further away from each others, one can study the correlation length of the clouds.

This has been recognized for over a decade (e.g. Shaver & Robertson 1983, Robertson & Shaver 1983). Observations of QSO pairs with projected separations from a few arcseconds to a few arcminutes yield interesting constraints on the size, physical structure and kinematics of galactic haloes, clusters and filaments. Indeed, new constraints have been obtained very recently on the extent of the Ly α complexes perpendicular to the line of sight at high (Smette et al. 1992, 1995, Bechtold et al. 1994, Dinshaw et al. 1994) and intermediate (Dinshaw et al. 1995) redshifts indicating that they could have sizes larger than 300 kpc. Such sizes are more indicative of a correlation length than of real cloud sizes

(Rauch & Haenelt 1996). This is consistent with the picture that the Ly α gas traces the potential wells of dark matter filamentary structures (Cen et al. 1994, Petitjean et al. 1995, Mückel et al. 1996, Hernquist et al. 1996, Miralda-Escudé et al. 1996). Large scale clustering of C IV systems (Heisler et al. 1989; Foltz et al. 1993) or damped systems (Francis & Hewett 1993, Wolfe 1993) have also been detected recently. The advent of 10m-class telescopes will boost this field since observation of faint QSOs in the same field will allow 3-D mapping of the baryonic content of the Universe via absorption line systems (Petitjean 1995).

2 The 1D correlation function

2.1 The Ly α forest

If the spatial distribution of the Ly α gas is related to the mass distribution it is of interest to measure the correlation of the absorption lines as a possible probe of the early stages of the gravitational clustering. Much work has been dedicated to the study of the 1D clustering properties of the Ly α lines along the line of sight to the quasars. Till recently no clustering in velocity space had been detected on scales $300 < \Delta v < 30000 \text{ km s}^{-1}$ (Sargent et al. 1980, Bechtold 1987, Webb & Barcons 1991). Most of the results were obtained using intermediate resolution spectroscopy. The number of lines observed at high resolution and with good S/N ratio has increased dramatically and it has been possible to investigate the clustering of the lines for different column density regimes (Rauch et al. 1992). Cristiani et al. (1995) have found significant clustering, with $\xi \sim 1$, at $\Delta v = 100 \text{ km s}^{-1}$ for lines with $\log N(\text{H I}) > 13.8$. For $\log N(\text{H I}) > 13.3$, a significant but much weaker signal, $\xi \sim 0.34$, is found. This result has been confirmed by Meiksin & Bouchet (1995) using neighbor probability distribution functions. They find also strong evidence for anticorrelation on the scale of $3\text{--}6h^{-1}\text{Mpc}$ (see also Hu et al. 1995). This overall is consistent with the idea that strong lines trace the dark matter filaments and weak lines are mostly found in underdense regions (Riediger et al. 1996).

2.2 The metal lines

It has been shown convincingly that metal line systems at $z < 1$ are associated with galaxies (Bergeron & Boissé 1991, Steidel 1993). It is thus not surprising to observe that metal line systems do cluster on scales $\Delta v < 600 \text{ km s}^{-1}$ (Sargent et al. 1988). There is however a problem when comparing clustering of absorption lines and clustering of galaxies. Indeed when observed at high spectral resolution, metal lines break up into individual components. The 1D correlation function can be fitted using the sum of two Gaussian distributions with $\sigma = 110$ and 525 km s^{-1} and $\sigma = 80$ and 390 km s^{-1} for the CIV systems at $z \sim 2.6$ (Petitjean & Bergeron 1994) and MgII systems at $z \sim 1$ (Petitjean & Bergeron 1990) respectively. The clustering at small velocities reflects motions of clouds within one individual halo whereas larger velocities indicate clustering of halos.

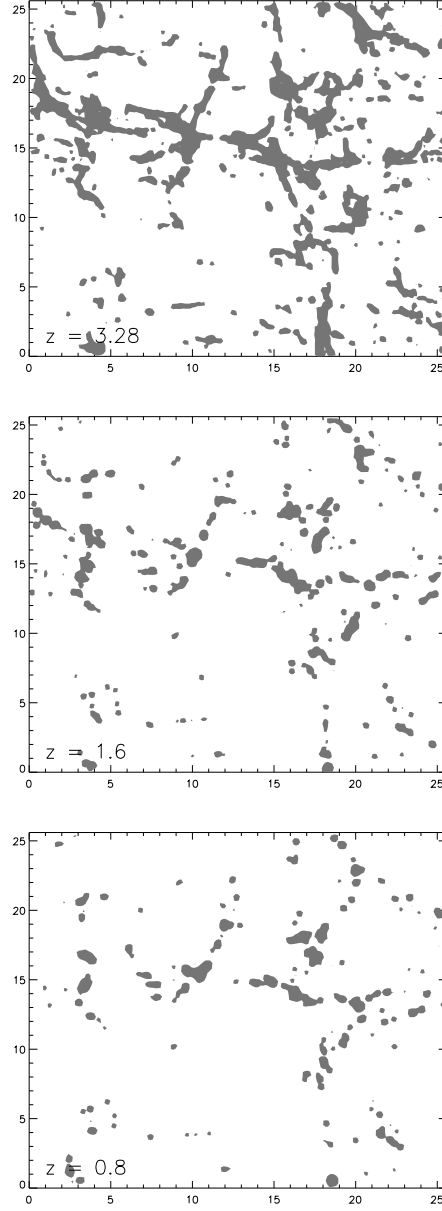


Fig. 1. Spatial distribution of Ly α clouds in a 2 Mpc slice of a (25 Mpc)³ simulation box at redshifts $z = (3.28, 1.6, 0.8)$ respectively. Gray contours show regions where $N(\text{H I}) > 10^{13} \text{ cm}^{-2}$ through the box.

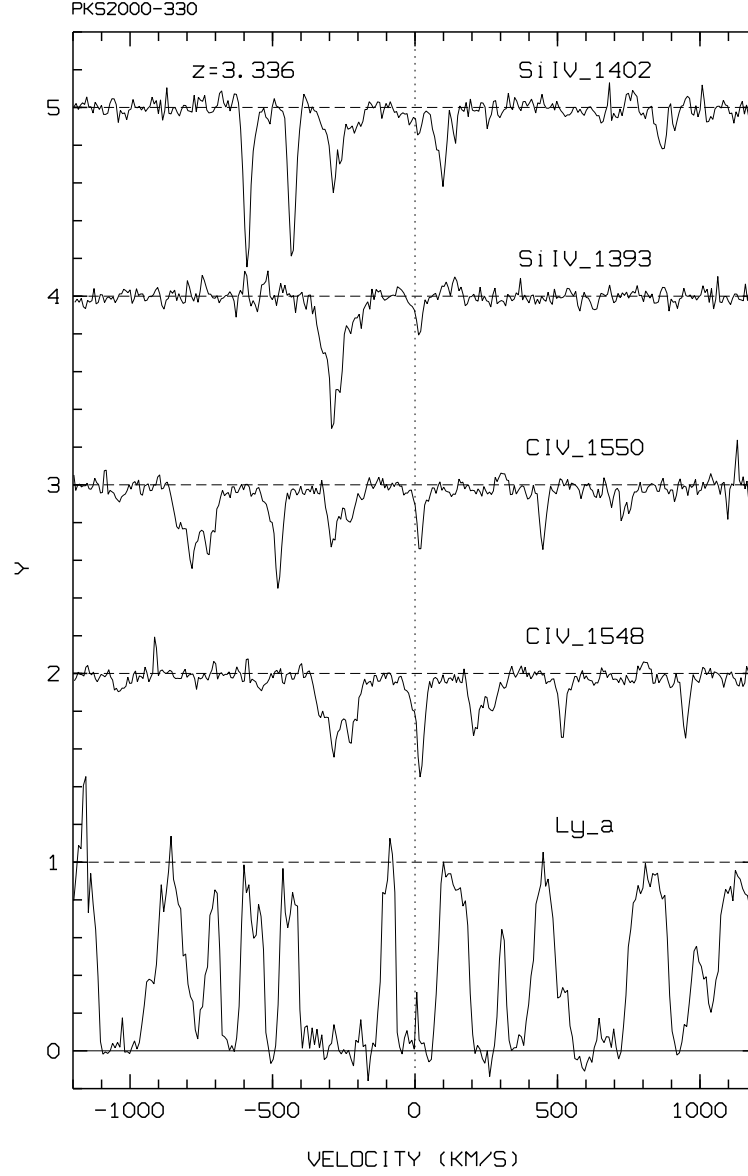


Fig. 2. Cluster of $\text{Ly}\alpha$ lines at $z \sim 3.336$ on the line of sight to PKS 2000-33 on a velocity scale. The corresponding C IV and Si IV lines are also shown.

It is thus clear that there is a difficulty in defining what part of the correlation function is related to clustering of haloes and what part is a consequence of motions of clouds within one halo. Only the first part of the function may be relevant for large scale analysis.

2.3 The weak C IV systems

Recent observations have shown that, at $z \sim 3$, C IV is found in 90% of the clouds with $N(\text{H I}) > 10^{15} \text{ cm}^{-2}$ and in about 50% of the clouds with $3 \times 10^{14} < N(\text{H I}) < 10^{15} \text{ cm}^{-2}$ (Songaila & Cowie 1996, Cowie et al. 1995). Several components are seen in most of these weak systems thus the correlation function shows a signal on scale smaller than 200 km s^{-1} . On this basis, Fernández-Soto et al. (1996) argue that the observed clustering is broadly compatible with that expected for galaxies and that most Ly α absorbers arise in galaxies. We could argue however, on the basis of the discussion in the previous section, that the signal detected in the correlation function has nothing to do with clustering of galaxies. What is seen is just the velocity structure of the Ly α gas inside large complexes.

Indeed a more attractive picture arise from the simulations showing that the Ly α absorption line properties can be understood if the gas traces the development of structures in the Universe (Cen et al. 1994, Petitjean et al. 1995, Mückel et al. 1996, Hernquist et al. 1996, Miralda-Escudé et al. 1996). This is illustrated in Fig. 1 showing the spatial distribution of the Ly α gas in a 2 Mpc slice of a $(25 \text{ Mpc})^3$ simulation box at redshifts $z = (3.28, 1.6, 0.8)$ respectively. In this picture, part of the gas is located inside filaments where star formation can occur very early in small halos that subsequently merge to build-up a so-called galaxy (Haehnelt et al. 1996). This gas contains metals. The remaining part of the gas has no metals and either is loosely associated with the filaments and has $N(\text{H I}) \gtrsim 10^{14} \text{ cm}^{-2}$ or is located in the underdense regions and has $N(\text{H I}) \lesssim 10^{14} \text{ cm}^{-2}$. In this picture it might happen that the line of sight intercepts a filament along its largest dimension. In such a case it is expected to see a cluster of strong Ly α lines with associated C IV lines of very different strengths. Such an observation is shown in Fig. 2. The data have been obtained with EMMI at the ESO NTT. The total integration time is 18 hours (Petitjean et al. 1996).

3 The 3D clustering

Recent studies indicate large scale clustering of absorbers. Heisler et al. (1989) detected significant correlation signal for C IV systems out to velocities of $\Delta v = 10000 \text{ km s}^{-1}$. Foltz et al. (1993) found an overdensity of C IV systems in the redshift range $1.57 \lesssim z \lesssim 1.69$ along the lines of sight to 6 QSOs. Francis & Hewett (1995) discovered two damped Ly α systems at similar redshifts in two lines of sight separated by $18h^{-1} \text{ Mpc}$ comoving. Most of the time however the signal is a consequence of an unusual overdensity of systems along a peculiar line of sight. Large samples of absorption systems have been used to investigate the 3D clustering properties of the absorbers (York et al. 1991, Tytler et al. 1993) with little success mostly due to lack of data.

3.1 An example: The field around Q1037-2704

In this context, the field surrounding the bright ($m_V = 17.4$) high redshift ($z_{\text{em}} = 2.193$) QSO Tol Q1037-2704 is quite promising. Jakobsen et al. (1986) were the first to note the remarkable similarity of the metal-line absorption systems in the spectra of Tol 1037-2704 and Tol 1038-2712 separated by 17.9° on the sky, corresponding to $4.3h_{100}^{-1}$ Mpc for $q_0 = 0.5$ at $z \sim 2$. They interpreted this as evidence for the presence of a supercluster along the line of sight to the QSOs. The fact that the number of metal-line systems in both spectra over the range $1.90 \leq z \leq 2.15$ is far in excess of what is usually observed has been considered as the strongest argument supporting this conclusion (Ulrich & Perryman 1986, Sargent & Steidel 1987, Robertson 1987). In a recent paper, Dinshaw & Impey (1996) have presented new data on four quasars in this field. They find that the velocity correlation function of the C IV systems shows strong and significant clustering for velocity separations less than 1000 km s^{-1} and up to 7000 km s^{-1} respectively. The spatial correlation function shows a marginally significant signal on scales of < 18 Mpc. They conclude that the dimensions of the proposed supercluster are at least $30 h^{-1}$ Mpc on the plane of the sky and approximately $80 h^{-1}$ Mpc along the line of sight. Moreover, by an analysis of the metal content and ionization state of several C IV complexes in Q1037-2704, Lespine & Petitjean (1996) have shown that the gas lies in intervening systems, supporting the presence of a coherent structure of supercluster dimensions.

3.2 Clustering of absorbers with VLT

The best approach to study clustering of absorbers is to search a small field for a large number of quasars and to identify the absorption systems in the quasar spectra. This will allow 3D mapping of the baryonic content of this part of the Universe. The major limitation is that the number of quasars per square degree is large enough to yield interesting conclusions at a magnitude prohibitively large to achieve adequate spectroscopy on 4 m class telescopes.

The possible VLT project would thus include :

- Deep imaging in broad bands with FORS or EMMI at the NTT to select QSO candidates. These images could be used for a parallel programme to detect galaxies at high z .
- Low resolution spectroscopy with FORS to confirm the candidates. This could be part of a programme aimed at determining the luminosity function of AGNs.
- Intermediate resolution ($m_{\text{QSO}} < 22.5$) and high resolution ($m_{\text{QSO}} < 19$) spectroscopy of the QSOs with FUEGOS and UVES for the brightest to study the absorptions.
- Multi-object spectroscopy in the field with FORS, NIRMOS and ISAAC to identify the associated galaxies.

Table 1 gives the number of QSOs expected in a one-degree field (Hartwick & Shade 1990) and the mean number of absorbers, with $w_{\text{obs,lim}} > 0.2 \text{ \AA}$, per line of sight. These numbers are indicative and take into account various observational

Table 1. One degree field, $w_{\text{obs,lim}} > 0.2 \text{ \AA}$

	Nb of QSOs			Nb of absorbers per QSO		
	$m < 21$	22	22.5	C IV	Ly α	Mg II
$0 < z < 2.2$	33	74	129	5		0.7
$0 < z < 2.2$	7	20	32	7	100	0.9

limitations. It is clear that one would like to observe the largest number of QSOs in the field. A compromise between this number and a reasonable amount of observing time should be found. However for a random spatial distribution of the QSOs, a number of hundred QSOs in the field seems adequate leading to primarily targetting $m < 22$ QSOs. The exposure time needed to obtain spectra of S/N ratio of 20 at a resolution of $R \sim 5000$ (thus $w_{\text{obs,lim}} \sim 0.2 \text{ \AA}$) on a $m = 22$ QSO is about 30 hours. This is large but the use of the MOS capabilities reduces the effective observing time requested to achieve the project. In this prospect the instrument providing the largest field, thus FUEGOS, should be used. Only six FUEGOS settings will be needed.

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